COLLIDER SEARCHES FOR X17 AND OTHER LIGHT GAUGE BOSONS

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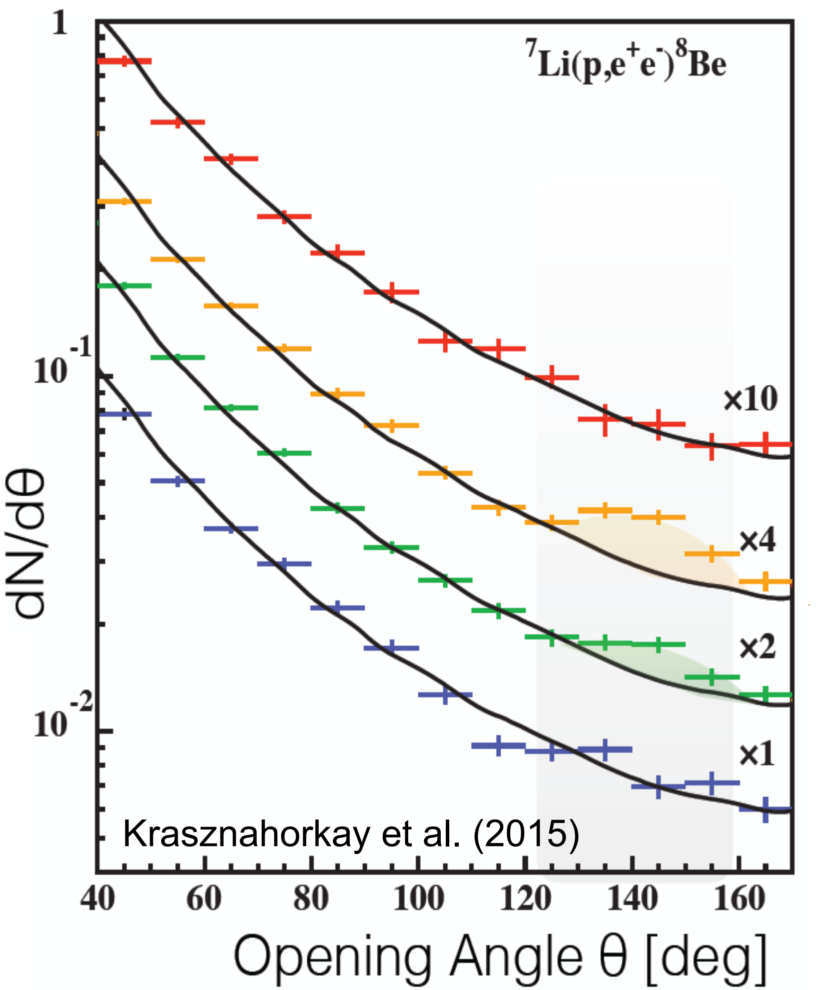
THE ATOMKI ANOMALY

- The ATOMKI ^{8}Be is the most interesting anomaly to appear in the last several years.

- Key considerations for a BSM theorist
  - $\sim 7\sigma$ statistical significance – not likely to disappear with more data
  - A bump, not a general excess
  - Rises and falls as one goes through resonance
  - Fit improves drastically with the introduction of a new particle
  - No compelling SM explanation
    Zhang, Miller (2017); Viviani et al. (2021)
  - No experimental problem identified

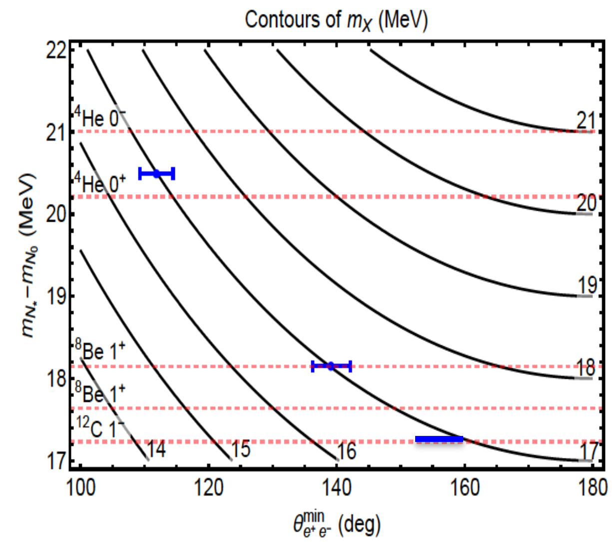


- And last, in general terms, it fits beautifully with current ideas for BSM physics and cosmology that motivate weakly interacting, light particles.

CONFIRMATIONS OF THE ATOMKI ANOMALY

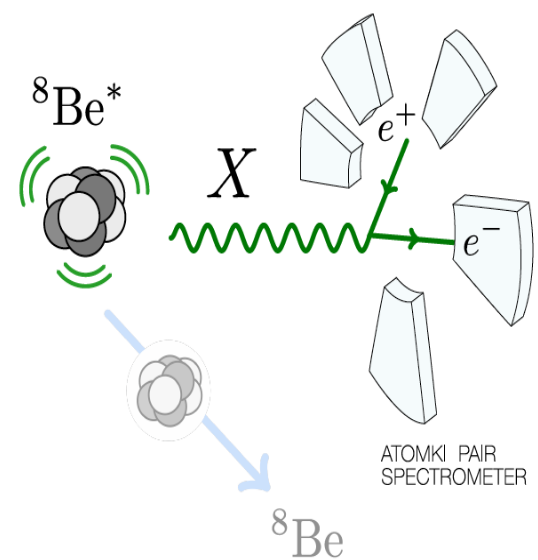
- The ^{8}Be anomaly has now been strengthened by supporting observations in other nuclear decays, and other experiments
  - ^{4}He from ATOMKI 2019
  - ^{12}C from ATOMKI 2022
  - ^{8}Be from HUS 2023 (reported here!)

    See talks of Kraznahorkay, Anh
  - The opening angle excess changes exactly as required for the X17 explanation



Feng, Tait, Verhaaren (2020)

- The ^{8}Be anomaly has also generated many works on possible BSM interpretations
  - It is not at all easy to explain all of these data without violating 70 years of constraints on ~17 MeV particles
  - X cannot be a scalar
  - X cannot be a dark photon

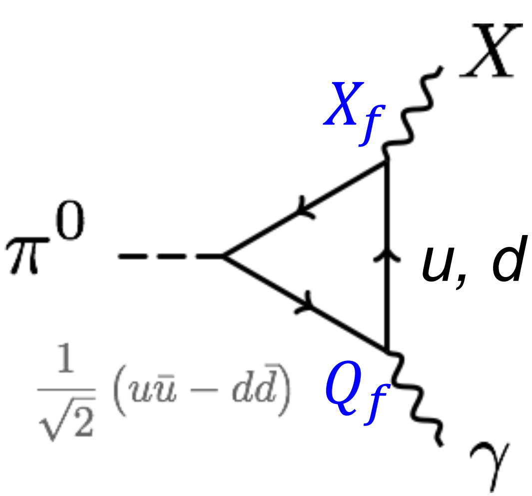


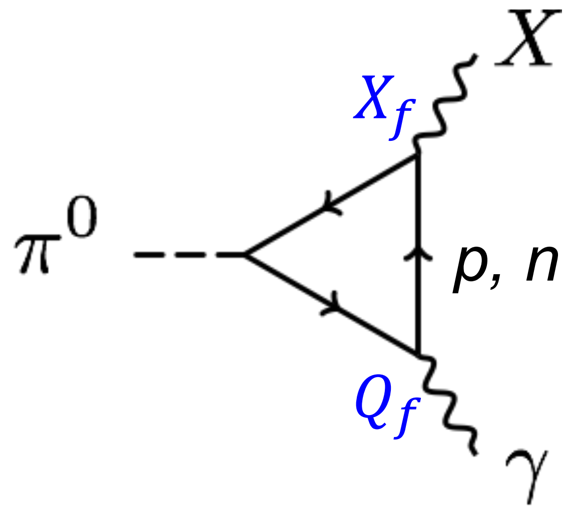
Tanedo (2016)

Feng, Fornal, Galon, Gardner, Smolinsky, Tait, Tanedo, 1604.07411, *Phys. Rev. Lett. 117, 071803 (2016)*; 1608.03591, *Phys. Rev. D 95, 035017 (2017)*

THE PROTOPHOBIC GAUGE BOSON

- One explanation that does work is the protophobic gauge boson.
- Among the dominant constraints on 17 MeV particles are null results from searches for exotic pion decays $\pi^0 \rightarrow X\gamma \rightarrow e^+ e^- \gamma$.





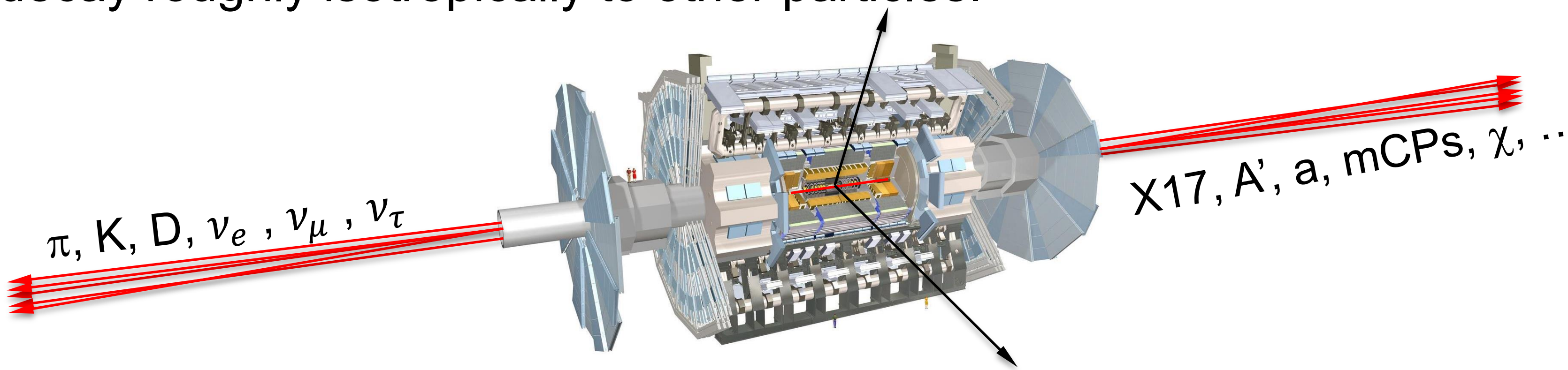
- This is eliminated if $Q_u X_u - Q_d X_d \approx 0$ or $2X_u + X_d \approx 0$ or $X_p \approx 0$.

- A protophobic gauge boson with couplings to neutrons and electrons, but suppressed couplings to protons and pions, can explain the ^{8}Be signal without violating other constraints, and it simultaneously explains both the location of the ^{4}He excess *and* the size of the excess.

Feng, Fornal, Galon, Gardner, Smolinsky, Tait, Tanedo (2016); Feng, Tait, Verhaaren (2020)

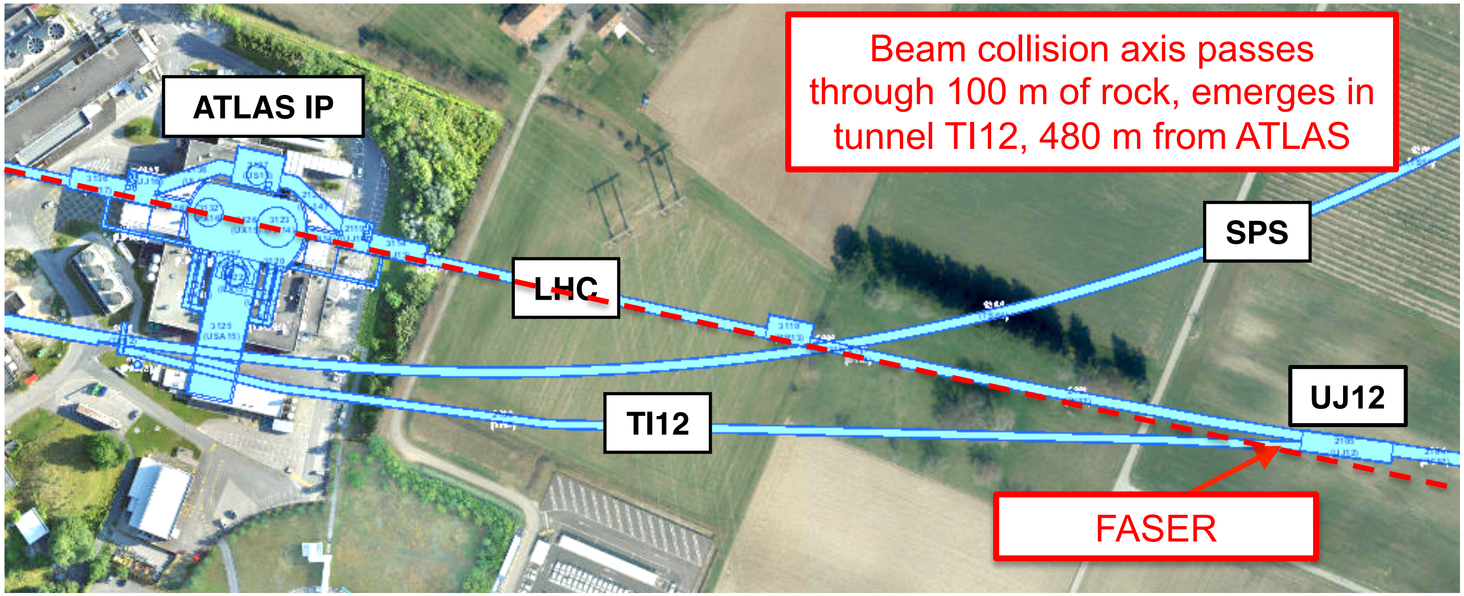
LIGHT GAUGE BOSONS AT COLLIDERS?

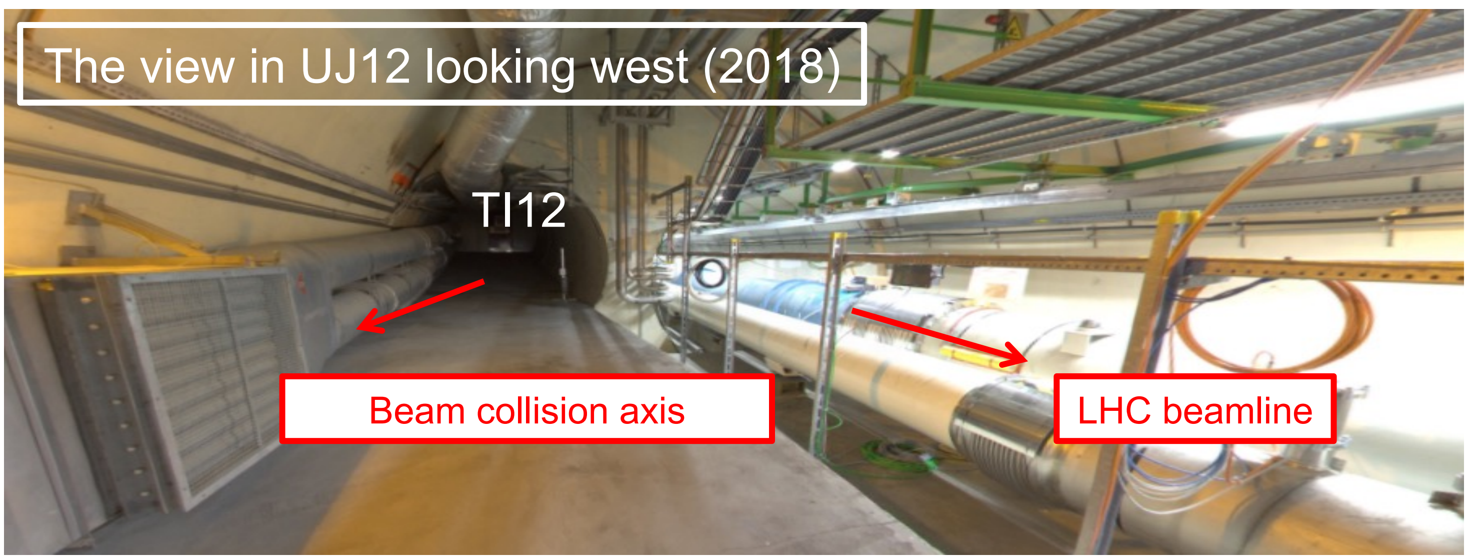
- X17 and other light, weakly interacting gauge bosons are produced in large numbers at the LHC and other colliders.
- Unfortunately, ATLAS, CMS, and the other large detectors are optimized to detect heavy particles, which are produced at low velocity and then decay roughly isotropically to other particles.



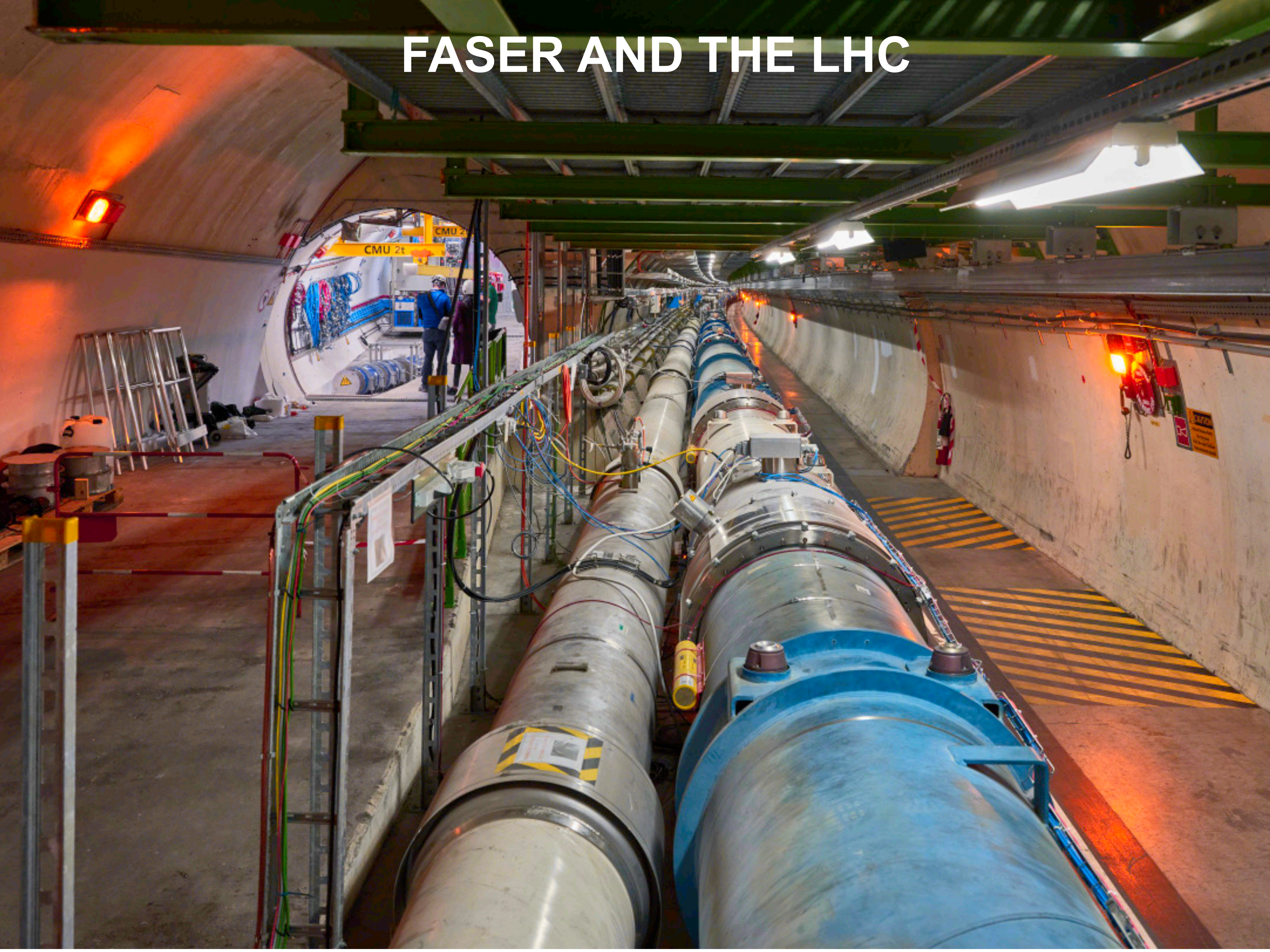
- But high-energy light particles are dominantly produced in the forward direction and escape through the blind spots of these detectors.
  - This is true for all known light particles: pions, kaons, D mesons, neutrinos.
  - It is also true for many hypothetical new particles: X17 gauge bosons, dark photons, dark scalars, HNLs, ALPs, milli-charged particles, dark matter, …
- These blind spots are the Achilles heels of the large LHC detectors.

FASER: FORWARD SEARCH EXPERIMENT





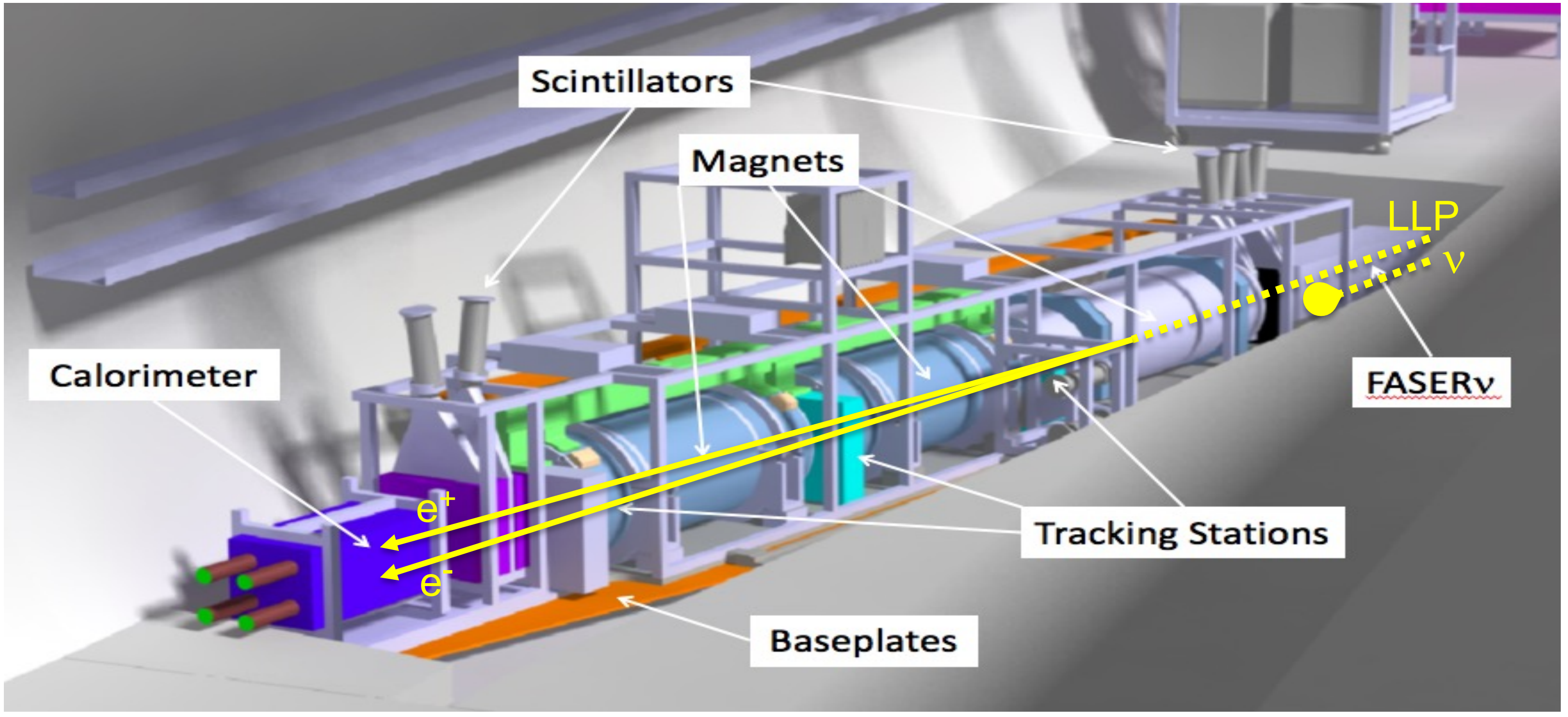
FASER AND THE LHC




FULLY INSTALLED FASER DETECTOR
2t
PA-1811
FASER
FRAGILE
DO NOT TOUCH

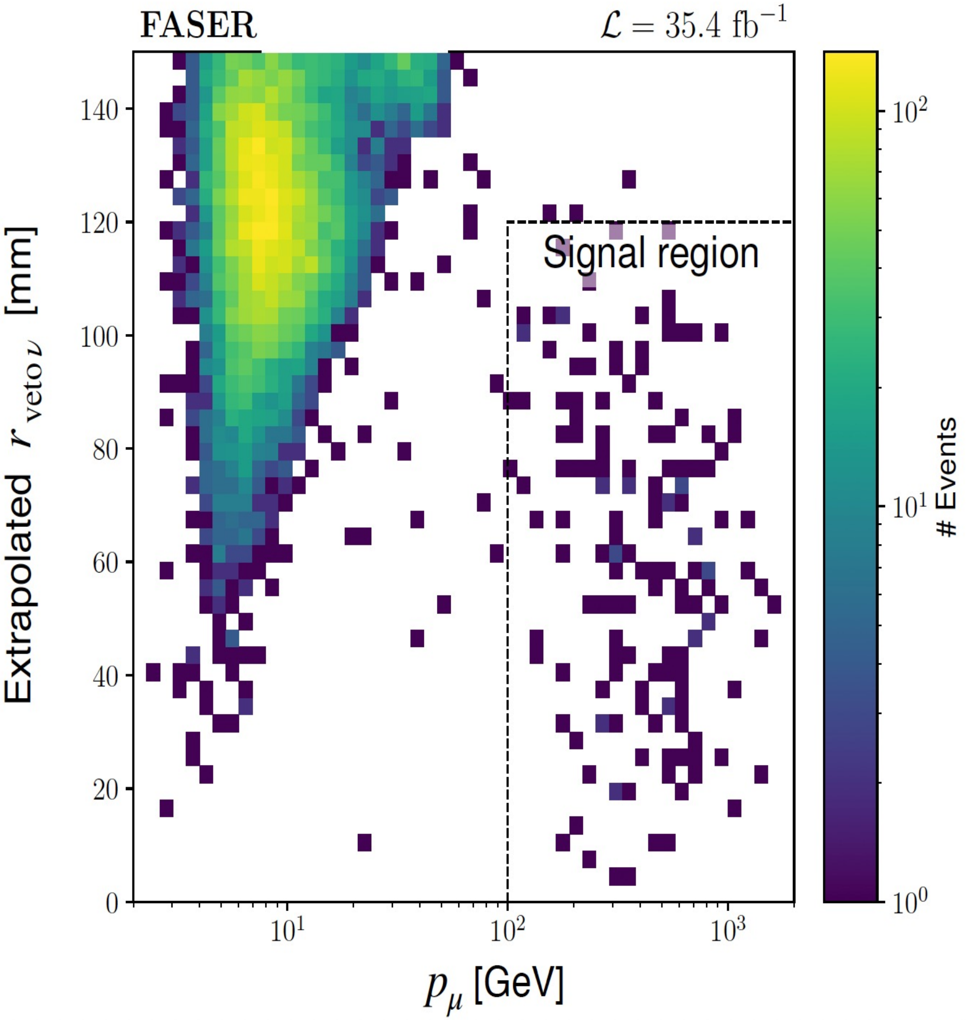
SIGNALS AT FASER

- Light gauge bosons: Nothing incoming and 2 ~TeV, e+/e- tracks pointing back to the ATLAS IP: a "light shining through (100 m-thick) wall" experiment.
- Collider neutrinos: Nothing incoming and a high energy lepton seen in the detector from $\nu_{e,\mu} N \to (e, \mu)\, X$.
- Scintillators veto incoming charged tracks (muons), magnets split the charged tracks, which are detected by tracking stations and a calorimeter.



COLLIDER NEUTRINO RESULTS

- Neutrinos provide a proof of principle for BSM searches
  - $\pi^{\pm} \to \nu_\mu$
  - $\pi^0, \eta \to A', X17, \ldots$
- After unblinding 2022 data, we found 153 neutrino signal events
  - Estimated background: < 1 event
- 1st direct observation of collider neutrinos; of great interest on their own
  - Signal significance of ~16σ
  - Muon charge → both ν and $\bar{\nu}$
  - These include the highest energy ν and $\bar{\nu}$ interactions ever observed from a human source

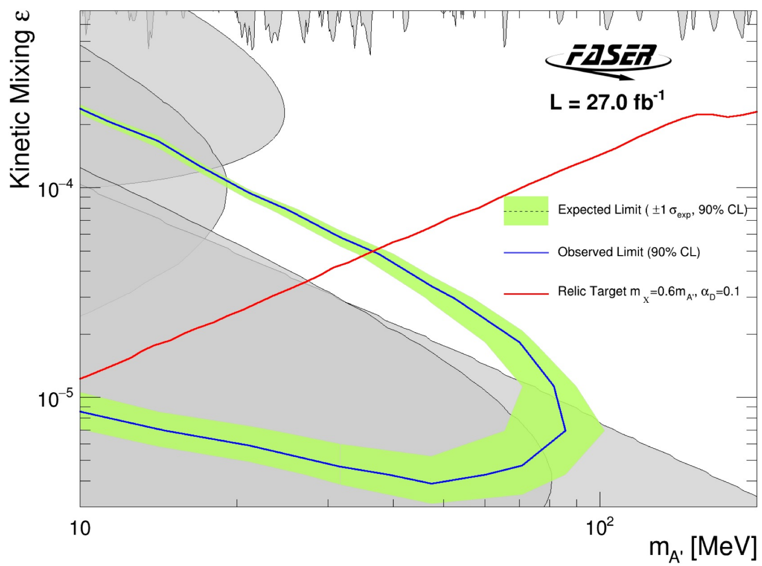


FASER Collaboration (2303.14185, Physical Review Letters)

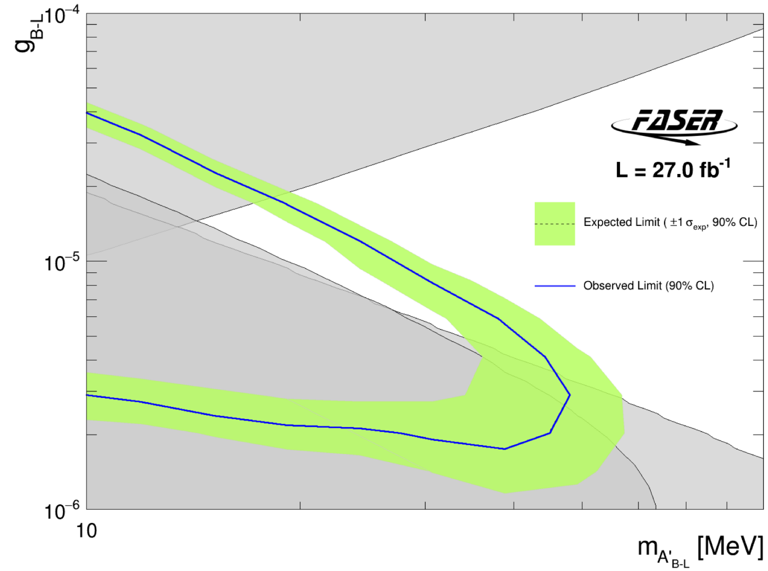
LIGHT GAUGE BOSON RESULTS

- After unblinding 2022 data, no events seen, FASER excluded previously unexplored parameter space for both dark photons and B-L gauge bosons.

- First new probe of light gageug bosons from low coupling since the 1990’s (roughly 30 times the sensitivity of previous experiments).



FASER Collaboration, 2308.05587



FASER Collaboration, 2308.05587

- These searches rely on production in π^0 decay, η decay, and bremsstrahlung off protons. For the protophobic X17, only η decay is operative, and we do not yet probe new parameter space, but ~10 times more luminosity and other improvements are expected by 2025.

SUMMARY

- The ATOMKI ^{8}Be is the most interesting anomaly to appear in the last several years.
- The original anomaly is now supported by additional observations in ^{4}He, ^{12}C, and at another facility.
- Tests from other sources, other approaches are of paramount importance; see the many other talks at this conference.
- Collider searches for new light gauge bosons are now underway at the LHC at the FASER experiment.
- Based on 2022 data, new bounds on light dark photons and B-L gauge bosons have been announced recently by FASER.
- For the protophobic X17, we do not yet probe new parameter space, but we expect ~10 times more luminosity and other improvements in LHC Run 3 by 2025.